Laser spectroscopy plays an important role in various applications, including environmental monitoring, meadical diagnostics (e.g. exhaled breath analysis) or industrial process control. After more than 30 years of development scientists can use compact semiconductor-based laser sources and thermoelectrically cooled (TEC) detectors to analyze a given gas sample and detect selected species with sensitivities down to single parts in a million, a billion or, in some cases, even in a quadrillion. However, despite the significant progress in laser-based gas sensing in the last two/three decades, some challenges still remain. Examples include remote/stand-off gas sensing or detection of molecules which are missing (or have weak) absorption lines in the infrared region (e.g. hydrogen) – currently available technologies are not well suited for these scenarios. To address these issues in this proposal we will study novel techniques and configurations for laser-based gas sensing.

Within the frames of this project the successful PhD candidate will verify the hypothesis that heterodyne-based optical signal detection can be used to enhance the performance of techniques for laser-based gas sensing. Our main goal will be to gain knowledge about new sensing configurations and signal processing algorithms, understand their principles and demonstrate their properties and advantages in various experimental arrangements.

In optical heterodyne detection (OHD) the optical signal is mixed with another light wave called a 'local oscillator' (LO). The idea is similar to heterodyne detection often used at radio frequencies (RF). In the RF heterodyne detection, the signal and the local oscillator are mixed using a nonlinear element. Similarly, in the optical domain the mixing process is typically accomplished using a square-low photodetector. OHD allows to down-convert the optical frequency (ca. 200 THz) into the frequency range that can be easily processed by standard electronics (e.g. below 1 GHz). It also provides a gain: if the signal wave is weak one can use strong local oscillator to obtain signal enhancement. Last but not least, OHD gives access to the phase of the optical wave. Within the frames of this project we will demonstrate that these three properties of OHD can be used to improve the performance and enable novel configurations of laser spectroscopy for gas sensing.

Project is divided into two tasks during which we plan to study and investigate the basic principles of the proposed approaches. We expect that realization of this project will help to gain new knowledge related to gas sensing and leak detection. In a long term this knowledge will result in new sensing techniques with improved performance comparing to the state-of-the-art. We believe that in 5 to 10 years after completion of the project these new methods may become tools in other fields, spanning from fundamental research, through environmental monitoring and medical applications to gas leak detection.

The important part of this project is the internship for the PhD student. In this project the student will have the opportunity to visit and work for six months in the laser sensing laboratory led by Prof. Gerard Wysocki at Princeton University. Princeton University is among the best academic schools in the world and it creates extremely inspiring and stimulating environment for students and researchers. The internship will give the PhD student a chance not only to develop scientifically but also to see how one of the best research group in the field is organized. This experience will surely pay off in her/his scientific career.